

19961028103

Oceanic Response to Atmospheric Pressure Forcing

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The purpose of this research is to attempt to accurately model the response of the sea surface height to the inverted barometer forcing. The impetus for this research is twofold: to better understand the nature of this effect and to apply these values as improved corrections to satellite altimetry records. Currently corrections are made to the altimetry record employing a model that makes assumptions of a static atmosphere in equilibrium. These assumptions have the potential to create errors. To improve this, it was decided to employ a barotropic numerical ocean model. A North Pacific model domain was selected because of the availability of both a large deep ocean basin and numerous adjacent marginal and semi-enclosed seas. Model runs are also being completed to analyze not only the surface pressure's effects, but also any induced influence in conjunction with the winds. Analysis of some preliminary 1 month runs showed the errors to the static response in the semi-enclosed and marginal seas to be much higher than that experienced in the open basin, and in some locations the error was of a comparable magnitude. Two year runs (1993-1994) are in the process of being completed and analyzed more fully. The length and time were selected to provide information of potential annual signals and the T/P mission, respectively. The analysis includes standard deviation, Fourier Transforms, wavelets and principal component analysis (EOF's), with emphasis on the semi-enclosed and marginal seas. Analysis to this point shows the errors to the static response in these regions to be affected by each basin's bathymetry, shape, and flow constraints. The analysis techniques employed help to understand the specifics of these characteristics. The principal component analysis will be employed in conjunction with T/P altimetry data.

1 Scientific Description

The purpose of this research is to attempt to accurately model the response of the sea surface height to atmospheric pressure forcing or the inverted barometer effect. These results can then be put to two uses: First the results can be studied to attain a better understanding of the effect. This research will primarily be concerned with "yellow-water" oceanography or the semi-enclosed and marginal seas and shelf regions. This is because these areas have largely been neglected in this field of study and as expected, preliminary results have shown the response to be far greater in these regions and less predictable. Second, once the inverted barometer can be accurately modeled, the results can be used as a correction to the altimeter record. The removal of these values from the altimetry GRD's will allow scientists to clearly study the remaining oceanographic features.

The inverted barometer effect is described as an inverse response of the sea surface height to changes in atmospheric pressure. The relationship is derived from the hydrostatic equa-

tion. Allowing for average values produces a relationship of a 1cm increase in sea surface height for each 1mb drop in ambient atmospheric pressure. The existence of this effect has been demonstrated both through the use of tide guages and altimetry data.

In the derivation of this relationship some assumptions are made. Namely that the atmospheric system is stationary and that there is sufficient time for the entire system to reach a state of equilibrium. Of course these conditions are rarely if ever achieved in our earth's constantly changing environment, thus inducing errors to this "static" appoximation. Currently, this is the method used in correcting the altimeter data record, with the assumption that the errors are small enough so as to be negligible. However the high precision of modern altimeters like T/P draw closer scrutiny to this assumption. To better model the total inverted barometer response it was decided to employ a numerical barotropic ocean model.

An initial set of three runs were completed. Each run was for the same 31 day time period beginning February 18, 1993. The three runs were made with the model forced by: (1) only surface pressure, (2) only wind stress, and (3) both surface pressure and wind stress. Differencing and comparison of these runs would be used to examine if there is any residual signal iduced by the interaction of the pressure and winds. This is an important consideration as the pressure cells are the source of winds. A North pacific domain from 10°S to 66°N was selected because it provides a large basin region with numerous semi-enclosed and marginal seas. The model has a resolution of 0.5° which is very high for this domain size. The model was sampled in two ways: twice per day at each grid point, and a simulated T/P altimeter was continually flown to sample the model.

These initial runs demonstrated the errors to generally be an order of magnitude less than the static inverted barometer response. In the shallower regions, however, the errors were seen to be of the same magnitude or greater than the static response. As expected a strong latitudinal response was seen; the magnitude of the pressure reponse was quite small in the equatorial zone (a few centimeters) and increased an order of magnitude in the higher latitudes. Also, comparing the results from the three runs showed that the combination of the wind and pressure in the model run did produce response that could not be accounted for by the response from just the wind forcing or pressure forcing alone . This reponse was minimal at best in the open ocean (generally 1cm or less), but became significant in the shallow regions such as the marginal and semi-enclosed seas. In some cases this contribution was of the same magnitude as the errors from the static case. Thus both forces are important in studying the oceans inverted barometer response, particuarly in shallow water.

A second run of one year (1993, so as to coincide with T/P) was then begun for pressure forcing only. The domain was also expanded to 20°S to allow a better equatorial analysis. When completed a much fuller analysis of the data was done than in the preliminary three runs. This analysis included statistics (standard deviation), Fourier transforms, and wavelets. This analysis was focused more on the behaviour in the semi-enclosed and marginal seas. The errors in these regions was seen to be as high or higher than the static response in some cases, especially the shallowest regions. The combination of these analysis techniques demonstrated the uniques responses generated by each individual semi-enclosed or marginal sea. It appears that bathymetry, shape, and flow-constraint into the region all have a bearing

on the response, with bathymetry dominating as it gets shallower. Figure 1 shows both the large error response in the shallow regions and also demonstrates the latitudinal nature of the inverted barometer response.

Currently the pressure only run is being extended to two years (1993-1994) and the other two scenarios: winds only and winds and pressure, are being completed to provide information on any potential annual signals. The aforementioned analysis techniques will then be applied to this data along with the addition of principal component analysis (EOF's). The principal component analysis will be done incorporating the T/P altimetry data. The results of this analysis should give both a better understanding of the ocean's inverted barometer response and aid in validating the model results. The use of the principal component analysis will begin with a study in the Yellow Sea. This research is being done in conjunction with Dr. Gregg Jacobs of the Naval Research Laboratory for part of a larger study on the Yellow Sea.

Finally the model results will be applied to the T/P data and a comparative analysis done to the currently accepted corrected data. This improved correction should improve the precision of the altimetry record for the remaining signals, especially in the shallow water regions.

2 Summary

Preliminary results from the model have demonstrated it to be a valuable tool in approximating the inverted barometer response. As expected, the errors from the static inverted barometer approximation, currently employed with satellite altimetry, are much larger in the shallow regions such as marginal and semi-enclosed seas. The numerous analysis techniques brought to bear on the model data indicate that the bathymetry, shape, and flow constraint all work to influence this response. It has also been seen that a response is induced through the interaction of the winds with the surface pressure. Further analysis of this phenomenon must be carried out to better understand it. The better understanding of this effect and the improved modeling of it will aid the analysis of the remaining signal in the data of satellite altimeters, especially the high precision data of T/P.

3 Papers and Presentations

Kantha, L. H., K. R. Whitmer, and G. H. Born, "The Inverted Barometer Effect in Altimetry: A Study in the North Pacific", *TOPEX/POSEIDON Res. News*, 2, 18-23, March, 1994.

Whitmer, K. R. and L. H. Kantha, "Oceanic Response to Atmospheric Pressure Forcing in the North Pacific", presented at *AGU 1994 Ocean Sciences Meeting*, San Diego, CA, 1994.

Whitmer, K. R. and L. H. Kantha, "Oceanic Response and Analysis of the Inverted Barometer Effect in the North Pacific", presented at *1995 IUGG Meeting*, Boulder, CO, 1995.

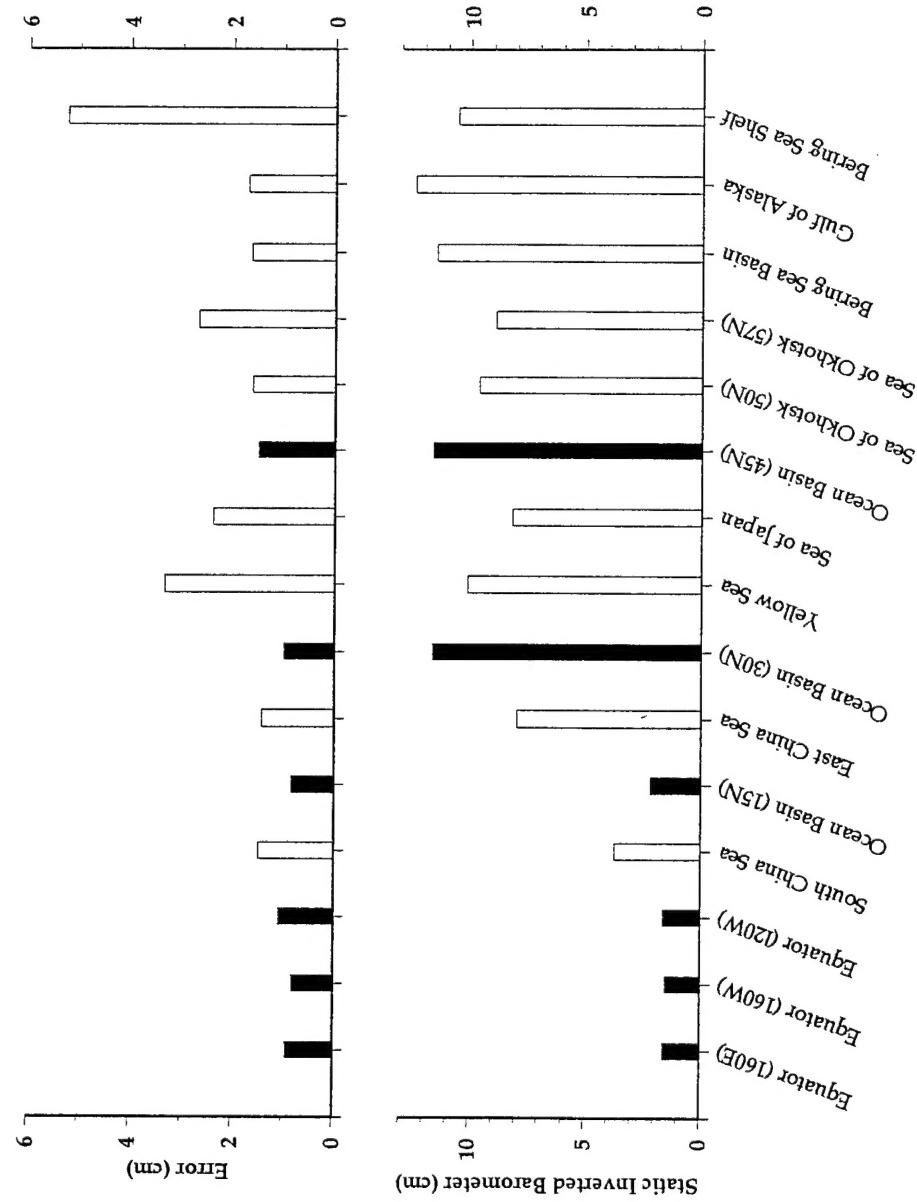


Figure 1: The standard deviation of: the traditional or static inverted barometer (bottom), and the associated errors as predicted by the numerical model (top), are plotted for various positions throughout the North Pacific domain. Deep ocean basin locations are plotted in black and semi-enclosed and marginal sea points are white. Locations are arranged in order of ascending latitude. Note that different scales are employed for the two quantities.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED	
	1996	Contract Report	
4. TITLE AND SUBTITLE Oceanic Response to Atmospheric Pressure Forcing			5. FUNDING NUMBERS
			Job Order No.
			Program Element No. 062435N
			Project No.
			Task No.
			Accession No.
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Colorado at Boulder Campus Box 431 Boulder, CO 80309-0431			8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Naval Research Laboratory Oceanography Division Stennis Space Center, MS 39529-5004			10. SPONSORING/MONITORING AGENCY REPORT NUMBER NRL/CR/7320-96-0002
11. SUPPLEMENTARY NOTES Contract No. N00014-94-1-G905			
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.		12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) The purpose of this research is to attempt to accurately model the response of the sea surface height to the inverted barometer forcing. The impetus for this research is twofold: to better understand the nature of this effect and to apply these values as improved corrections to satellite altimetry records. Currently corrections are made to the altimetry record employing a model that makes assumptions of a static atmosphere in equilibrium. These assumptions have the potential to create errors. To improve this, it was decided to employ a barotropic numerical ocean model. A North Pacific model domain was selected because of the availability of both a large deep ocean basin and numerous adjacent marginal and semi-enclosed seas. Model runs are also being completed to analyze not only the surface pressure's effects, but also any induced influence in conjunction with the winds. Analysis of some preliminary 1 month runs showed the errors to the static response in the semi-enclosed and marginal seas to be much higher than that experienced in the open basin, and in some locations the error was of a comparable magnitude. Two year runs (1993-1994) are in the process of being completed and analyzed more fully. The length and time were selected to provide information of potential annual signals and the T/P mission, respectively. The analysis includes standard deviation, Fourier Transforms, wavelets and principal component analysis (EOF's), with emphasis on the semi-enclosed and marginal seas. Analysis to this point shows the errors to the static response in these regions to be affected by each basin's bathymetry, shape, and flow constraints. The analysis techniques employed help to understand the specifics of these characteristics. The principal component analysis will be employed in conjunction with T/P altimetry data.			
14. SUBJECT TERMS satellite altimetry, ocean modelling, wavelets, bathymetry, and TOPEX/Poseidon			15. NUMBER OF PAGES 4
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT SAR